

MULTIMEDIA



UNIVERSITY

STUDENT ID NO

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MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2017/2018

EEE7256 – DEVICE PROCESSING AND FABRICATION

(Master of Electrical and Electronic Engineering)

13 OCTOBER 2017

2.30 p.m. - 5.30 p.m.

(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 7 pages with 3 Questions only.
2. Attempt **ALL** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

QUESTION 1

- (a) The majority of the silicon (Si) crystals for industrial applications are grown using Czochralski (CZ) technique due to the speed of production. With schematic aids, discuss the operation principle of the CZ technique in the growth of Si crystals. [1.5+4.5 marks]
- (b) Cleanrooms are specially constructed enclosed spaces where the contaminants are kept within specified limits. Describe four fundamental strategies which apply to any design for cleanrooms. [8 marks]
- (c) Describe the requirements for the cleanroom facilities for the fabrication of microelectronic devices. Identify the "class" of the cleanroom standard and suggest four main instruments to be installed in the cleanroom designed for the manufacturing of microelectronic devices. [4 marks]
- (d) A boule of single crystal Si is pulled from the melt, which is contained in a crucible of a CZ crystal puller. The dopant is Phosphorus (P). The Si boule is sliced into thin sheet of wafers after the pulling process. The wafer taken from the top of the Si boule has a doping concentration of $2 \times 10^{15} \text{ cm}^{-3}$. The segregation coefficient (k) for P is given as 0.35. Determine the doping concentration of the wafer taken from the position corresponding to 72% of the initial charge solidified. [2 marks]
- (e) Yield is the most important financial factor in producing integrated circuits in semiconductor manufacturing industries. Distinguish the following three manufacturing yield components:
- (i) Wafer yield
 - (ii) Probe testing yield
 - (iii) Final testing yield [3 marks]
- (f) The efforts in utilizing computer hardware and software technology to enhance manufacturing methods have led to the development of computer-integrated manufacturing of integrated circuits (IC-CIM) techniques. Describe the objectives of the design of the IC-CIM techniques. [2 marks]

Continued

QUESTION 2

- (a) The feature of semiconductors that makes them so useful for electronic devices is that their conduction properties can be changed by introducing small quantities of dopant atoms. Thermal diffusion and ion implantation are the methods to introduce impurities into intrinsic semiconductors.
- (i) Discuss the limitations of the thermal diffusion and ion implantation techniques in the doping process for the manufacturing of microelectronic devices. [10 marks]
- (ii) An implantation of boron dopant is performed onto a silicon wafer. The projected range of the implanted profile is 2000 Å. Take the standard deviation of the projected range as 500 Å. Determine the depth of peak of the implanted profile, and the peak concentration of the boron dopant for an implantation dose of 10^{11} cm⁻². [4 marks]
- (iii) An n-type silicon wafer has a uniform background concentration of 3×10^{16} cm⁻³. A solid solubility limited boron pre-deposition is performed at 920 °C for 30 minutes. The boron concentration at the surface is 2×10^{18} cm⁻³. The diffusion coefficient for boron at 920 °C is given as 1×10^{-14} cm²s⁻¹. Determine the junction depth following the boron pre-deposition process. Refer to page 6 for the error function table. [8 marks]
- (b) Physical vapor deposition is a thin film deposition technique to apply thin films of material on growing substrates to form thin layers via heating (evaporation) or energetic ion bombardment (sputtering) mechanisms.
- (i) Compare the evaporation mechanism with the sublimation mechanism in the context of physical vapor deposition in the semiconductor deposition process. [5 marks]
- (ii) Describe the reasons why the evaporation technique has been replaced by sputtering deposition technique in modern silicon technology processing. [4 marks]
- (iii) With the aid of a schematic diagram, discuss the operation principles of the sputtering deposition process. [2+5 marks]

Continued

QUESTION 2

- (c) Photolithography is the technology of choice for patterning the semiconductor devices with feature size in the range of micrometer. In photolithography, there are three printing techniques, namely, contact, proximity, and projection printing techniques.
- (i) With schematic aids, describe the characteristics of the contact and proximity printing techniques during the mask exposure and alignment process, respectively. [2+4 marks]
- (ii) Discuss the advantages and disadvantages of the contact and proximity printing techniques, respectively, in terms of the contamination on substrates and optical masks, and the resolution of the printing technique during the patterning process. [4 marks]
- (iii) In a photolithography system, a mask aligner uses an *i*-line source with a wavelength of 365 nm. If the photoresist thickness is 1.3 μm and the photoresist constant, k , is given as 0.75, determine the minimum feature size, W_{min} , that can be achieved using the contact printing technique, and the proximity printing technique with an air gap of 25 μm , respectively. [4 marks]
- (d) Briefly describe the technical requirements for etching in ultralarge-scale integrated (ULSI) semiconductor circuits. [8 marks]

Continued

QUESTION 3

The cross-sectional view of a planar N-P-N bipolar junction transistor (BJT) on N-type silicon substrate is given in Figure 3.

- (i) Design a fabrication process for the BJT depicted in Figure 3 by providing neat sketch and description of your fabrication processing flow. [14 marks]
- (ii) How many masks are required in the patterning of the BJT? [1 mark]

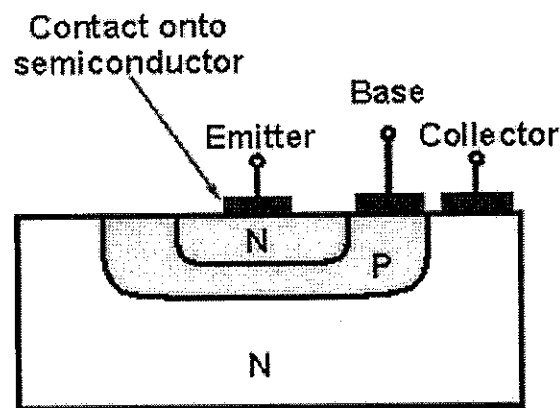


Figure 3: Schematic cross-section of a planar N-P N bipolar junction transistor (BJT).

Continued

Values of the error function $\text{erf}(t) = \frac{2}{\sqrt{\pi}} \int_0^t e^{-a^2} da$

t	0	1	2	3	4	5	6	7	8	9
0.0	0.000	0.0113	0.0226	0.0338	0.0451	0.0564	0.0676	0.0789	0.0901	0.1013
0.1	0.1125	0.1236	0.1348	0.1459	0.1569	0.1680	0.1790	0.1900	0.2009	0.2118
0.2	0.2227	0.2335	0.2443	0.2550	0.2657	0.2763	0.2869	0.2974	0.3079	0.3183
0.3	0.3286	0.3389	0.3494	0.3593	0.3694	0.3794	0.3893	0.3992	0.4090	0.4187
0.4	0.4284	0.4380	0.4475	0.4569	0.4662	0.4755	0.4847	0.4937	0.5027	0.5117
0.5	0.5205	0.5292	0.5379	0.5465	0.5549	0.5633	0.5716	0.5798	0.5879	0.5959
0.6	0.6039	0.6117	0.6194	0.6270	0.6346	0.6420	0.6494	0.6566	0.6638	0.6708
0.7	0.6778	0.6847	0.6914	0.6981	0.7047	0.7112	0.7175	0.7238	0.7300	0.7361
0.8	0.7421	0.7480	0.7538	0.7595	0.7651	0.7707	0.7761	0.7814	0.7867	0.7918
0.9	0.7969	0.8019	0.8068	0.8116	0.8163	0.8209	0.8254	0.8299	0.8342	0.8385
1.0	0.8472	0.8468	0.8508	0.8548	0.8586	0.8624	0.8661	0.8698	0.8733	0.8768
1.1	0.8802	0.8835	0.8868	0.8900	0.8931	0.8961	0.8991	0.9020	0.9048	0.9076
1.2	0.9103	0.9130	0.9155	0.9181	0.9205	0.9229	0.9252	0.9275	0.9297	0.9319
1.3	0.9340	0.9361	0.9381	0.9400	0.9419	0.9438	0.9456	0.9473	0.9490	0.9507
1.4	0.9523	0.9539	0.9554	0.9569	0.9583	0.9597	0.9611	0.9624	0.9637	0.9649
1.5	0.9661	0.9673	0.9684	0.9695	0.9706	0.9716	0.9726	0.9736	0.9746	0.9755
1.6	0.9764	0.9772	0.9780	0.9789	0.9796	0.9804	0.9811	0.9818	0.9825	0.9832
1.7	0.9838	0.9844	0.9850	0.9856	0.9861	0.9867	0.9872	0.9877	0.9882	0.9886
1.8	0.9891	0.9895	0.9899	0.9904	0.9907	0.9911	0.9915	0.9918	0.9922	0.9925
1.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
2.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
2.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
2.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
2.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
2.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
2.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
2.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
2.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99998	.99998	.99998	.99998	.99998	.99998	.99999	.99999	.99999

for $t > 3$ $\text{erf}(t) \approx 1 - \frac{1}{\sqrt{\pi} t} \exp(-t^2)$

$\text{erfc}(t) = 1 - \text{erf}(t)$

Continued

APPENDIX**Physical Constants:**

Avogadro number, $N_{avo} = 6.02217 \times 10^{23} \text{ mol}^{-1}$
 Boltzmann constant, $k = 1.380622 \times 10^{-23} \text{ J K}^{-1} = 8.61712 \times 10^{-5} \text{ eV K}^{-1}$
 Electronic charge, $e = 1.60219 \times 10^{-19} \text{ C}$
 Electron rest mass, $m_0 = 9.10956 \times 10^{-31} \text{ kg}$
 Electron volt, $1 \text{ eV} = 1.60219 \times 10^{-19} \text{ J}$
 Si yield strength $= 2 \times 10^7 \text{ dynes cm} = 7 \text{ GPa}$
 Latent heat of fusion for Si, $L = 340 \text{ cal g}^{-1}$
 Thermal conductivity of Si, $k = 0.21 \text{ W cm}^{-1} \text{ }^\circ\text{C}^{-1}$
 Amount of heat of 1 calorie $= 4.14 \text{ J}$
 Density of bulk Si $= 2.33 \text{ g cm}^{-3}$
 Density of molten Si $= 2.53 \text{ g cm}^{-3}$
 Electric current of 1 A $= 1 \text{ Cs}^{-1}$
 Atomic mass unit of 1 amu $= 1.66053 \times 10^{-27} \text{ kg}$
 Magnetic flux density of 1 T $= 1 \text{ Wb m}^{-2} = 10^4 \text{ G}$
 Angstrom unit of 1 Å $= 1 \times 10^{-10} \text{ m} = 0.1 \text{ nm} = 1 \times 10^{-4} \text{ } \mu\text{m}$
 Permittivity of free space $= 8.85 \times 10^{-14} \text{ F cm}^{-1}$
 Pressure of 1 Torr $= 133.32237 \text{ Pa}$

Formulas:

$C(x,t) = C_s \operatorname{erfc} \left[\frac{x}{2\sqrt{Dt}} \right]$	$N(x) = \frac{Q_o}{\sqrt{2\pi\Delta R_p}} e^{\left[-\frac{1}{2} \left(\frac{x-R_p}{\Delta R_p} \right)^2 \right]}$
$C(x) = \frac{Q}{\sqrt{\pi Dt}} e^{-\left(\frac{x}{2\sqrt{Dt}} \right)^2}$	$N(R_p) = \frac{Q_o}{\sqrt{2\pi\Delta R_p}} = N_p$
$x_j = 2\sqrt{Dt} \ln(N_o/N_B)$	$C_s = \frac{Q}{\sqrt{\pi Dt}}$
$x_j = 2\sqrt{Dt} \operatorname{erfc}^{-1}(N_B/N_o)$	$Q = 2C_s \sqrt{\frac{Dt}{\pi}}$
$k_0 = \frac{C_s}{C_i}$	$Q = \sqrt{2\pi} N_p \Delta R_p$
$W_{\min} = \sqrt{k\lambda g}$	$C = k C_0 (1-x)^{k-1}$
$W_{\min} = k \{ \lambda / NA \}$	

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